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Science and Technology (S&T) Roadmap Collaboration between SMC, NASA, and Government Partners

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National Security Space (NSS) presents multi-faceted S&T challenges. We must continually innovate enterprise and information management; provide decision support; develop advanced materials; enhance sensor technology; transform communication technology; develop advanced propulsion and resilient space architectures and capabilities; and enhance multiple additional S&T domains. These challenges are best met by leveraging advanced S&T research and technology development from a number of DoD agencies and civil agencies such as NASA. The authors of this paper have engaged in these activities since 2006 and over the past decade developed multiple strategic S&T relationships. This paper highlights the Office of the Space Missile Systems Center (SMC) Chief Scientist (SMC/ST) collaboration with the NASA Office of Chief Technologist (NASA OCT), which has multiple S&T activities that are relevant to NSS. In particular we discuss the development of the Technology Roadmaps that benefit both Civil Space and NSS. Our collaboration with NASA OCT has been of mutual benefit to multiple participants. Some of the other DoD components include the Defense Advanced Research Projects agency (DARPA), Air Force Research Laboratory (AFRL), Naval Research Laboratory (NRL), The USAF Office of Chief Scientist, the USAF Science Advisory Board (SAB), Space and Naval Warfare Systems Command (SPAWAR), and a number of other services and agencies. In addition, the human talent is a key enabler of advanced S&T activities; it is absolutely critical to have a strong supply of talent in the fields of Science Technology, Engineering, and Mathematics (STEM). Consequently, we continually collaborate with the USAF Institute of Technology (AFIT), other service academies and graduate schools, and other universities and colleges. This paper highlights the benefits that result from such strategic S&T partnerships and recommends a way forward that will continually build upon these achievements into the future.

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I. Enhanced Collaboration Driven by the 2010 United States National Space Policy (NSP)

The 2010 NSP[1] called for collaboration among international, commercial, civil, and national security space programs. This change in policy opened a wealth of collaboration opportunities, which will be discussed in this paper. Even prior to 2010, in 2006, the SMC Chief Scientist office collaborated with The Defense Advanced Research Projects Agency (DARPA) and served as the technical focusing agent for a number of efforts. This role involved serving on the government team of a number of programs, including System F6[2]. System F6 introduced independent, smaller, free-flying satellites (modules), which are interconnected via a wireless Internet Protocol (IP) network. This innovation introduced robustness and flexibility into the space enterprise, as modules can come and go in and out of the satellite cluster. Again, IP serves to increase the resilience and flexibility of this advanced fractionated space architecture. One of the immediate results of the 2010 space policy was the decision of NASA and DARPA to collaborate on technical challenges of mutual interest. The Manned Geostationary Orbit (GEO) Servicing (MGS) study was one such collaboration that we contributed to, and it is the focus of the next section.

Figure 1. The DARPA System F6 Concept

II. SMC-DARPA-NASA Collaboration - MGS

Since S&T investments have come under financial pressure in recent years, these S&T challenges are best met by leveraging advanced S&T research and development of a number of DoD agencies, as well as civil agencies such as NASA. The authors have engaged in these activities since 2006 and over the past decade developed and continually expanded multiple strategic S&T relationships. In 2010, we supported a NASA-DARPA collaboration on Manned GEO Servicing (MGS) study[31], which evaluated the concept of on-orbit human and robotic assisted servicing of satellites in GEO orbit. While NASA's mission is scientific and focused on space exploration, DARPA's mission is National Security Space (NSS). NASA is considering sending human explorers to other planets, such as Mars. Since GEO orbit is deeper in space than the low Earth orbit (LEO) where the International Space Station operates, MGS can advance human space exploration in understanding the challenges of operating in this different environment. Some of the challenges include extended periods of life support (weeks to months to years), humans exposed to the increased radiation environment in GEO, and the challenging propulsion requirements required to transfer from LEO orbit to GEO orbit and back from GEO to LEO, a transfer which involves possible extended periods in the high radiation environment of the Van Allen belts, especially if Solar Electric Propulsion (SEP) is used.

Since the NSS mission is capability focused, the NSS technical goals are to achieve on-orbit servicing at higher orbits and in particular within GEO. However the NSS preference would more likely focus on robotic on-orbit satellite servicing. This servicing would eliminate the daunting challenges of providing for extended periods of life support in high radiation environments. However, dexterous servicing of challenging tasks is beyond the scope of today's space robot technology. Simpler tasks such as refueling or opening an appendage such as a stuck solar array are closer to current capability; although to our knowledge, such simple on-orbit servicing tasks have not yet been demonstrated. Complex tasks such as external repair would be even more challenging to demonstrate. The most difficult tasks would involve repair of internal components. This type of repair would require on orbit "robotic-surgery," which would be among the most difficult tasks and well beyond the current state of the art.

Subsequently, DARPA initiated the Phoenix program in order to further advance robotic on-orbit servicing capabilities. SMC participated in some government team activities, which include proposal evaluation, transition planning, and overall program awareness. The Phoenix program benefited from the NASA-DARPA investment in the MGS program. In fact a number of the government team members such as the Naval Research Lab (NRL) have a key role within the program; in addition, this participation also leverages the previous DARPA investment in the Front-end Robotics Enabling Near-term Demonstration (FREND) program, which was performed by NRL.

III. Collaboration with the NASA Office of Chief Technologist (NASA OCT)

The NASA Office of Chief Technologist (NASA OCT) has multiple S&T activities that are relevant to NSS. Our collaboration with NASA OCT has been of mutual benefit to multiple participants. Our relationship with NASA OCT was further enhanced in 2014. We share with NASA OCT some of our S&T plans and assist NASA in reviewing the Technology Roadmaps that OCT oversees. Similar to our discussion of the NASA/DARPA MGS collaboration, there are common elements among the agencies especially within the pervasive S&T technologies, despite the fact that NASA has a science mission and the USAF has an NSS mission. These include propulsion, fractionated space architectures, on-orbit servicing, space dynamics and proximity operations, satellite operations, and ground system architectures, to name but a few technology areas. The next sections describe the NASA and SMC collaboration related to the area of Technology Roadmap development.

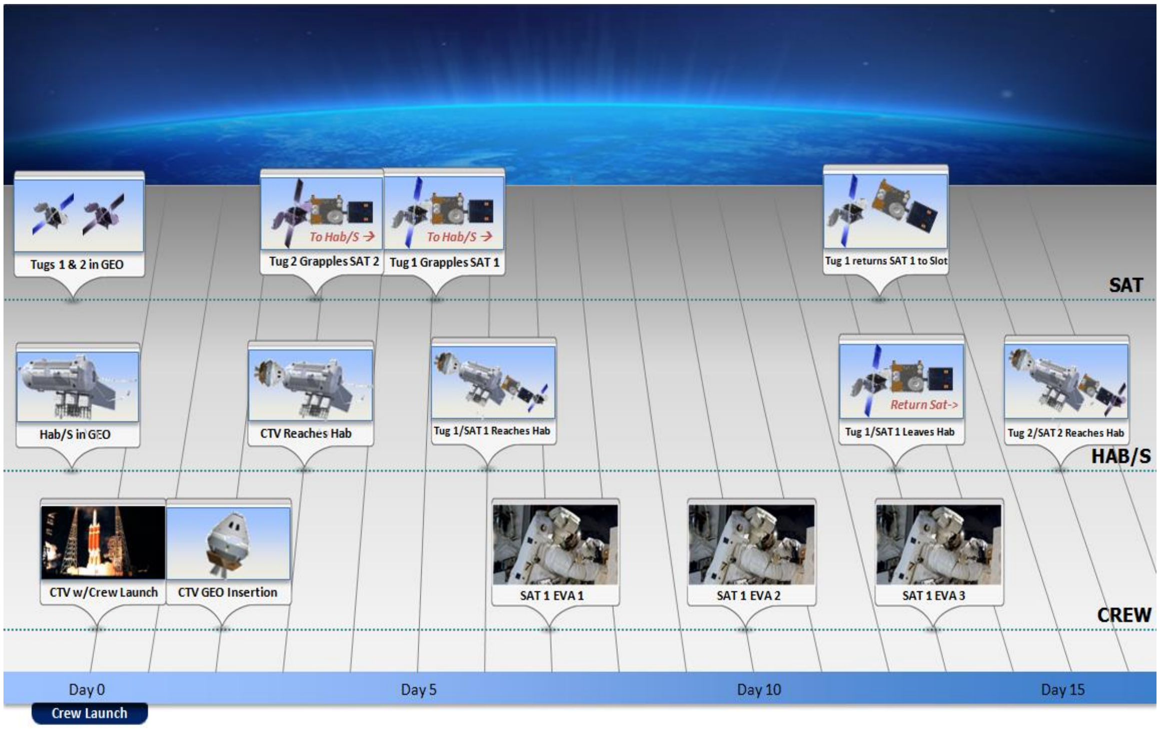

Figure 2. MGS Operational Concept

IV. NASA Technology Roadmap Development and Prioritization

NASA's most powerful tools for achieving mission success are teamwork and collaboration. Each element within NASA brings unique experience and important expertise. Consequently, when NASA began updating the NASA Technology Roadmaps, it encouraged participation by international, intergovernmental, academic, and industrial organizations. The NASA Technology Roadmaps are a set of documents that consider a wide range of needed technology candidates and development pathways for the next 20 years (2015-2035). The roadmaps are one element of an integrated Agency-wide technology portfolio management process (Figure 3) that prioritizes technologies, tracks investments, facilitates decision making, and manages the technology portfolio.

The effort to develop the Technology Roadmaps began in 2010 when NASA identified 14 space technology areas, which include the technologies that could enable NASA's spaceflight missions and their associated technical challenges. The first set of draft roadmaps covered technologies for both human exploration and scientific discovery. The National Research Council (NRC) performed an independent critique of the roadmaps and recommended priorities (ref. NASA Space Technology Roadmaps and Priorities: Restoring NASA's Technological Edge and Paving the Way for a New Era in Space, 2012). Using the NRC's input, top-down strategic guidance from the Executive Office of the President via Executive Orders, the National Science and Technology Priorities, and the NASA Strategic Plan, the technologies were prioritized in the NASA 2013 Strategic Space Technology Investment Plan (SSTIP). NASA executed the comprehensive plan, investing in technologies that optimized the benefits of key stakeholders including NASA's mission directorates, federal agencies, and the national economy.

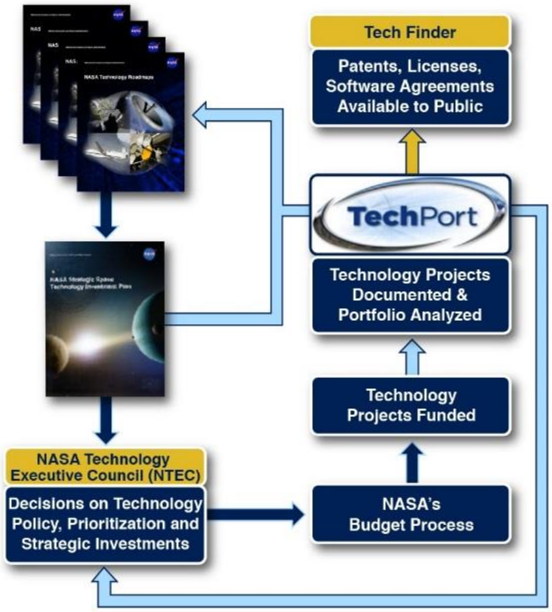

Figure 3. NASA Technology Portfolio Management Process

NASA hosted a Technical Interchange Meeting with invited professionals from academia, commercial industry, and other government agencies to gather input on NASA's technology portfolio management process, including enhancement of the Technology Roadmaps and prioritization of future work. Informed by stakeholders, NASA created a new systematic process to update and enhance the Technology Roadmaps and prioritization of technologies. The process used in developing the Technology Roadmaps is shown in Figure 4 and outlined here. This process included evaluating planned and conceptual Design Reference Missions (DRMs) from each of NASA's mission directorates. Using these DRMs and with support from NASA's Human Architecture and Systems Maturation Teams, Science Decadals, and the Aeronautics Strategic Implementation Plan, NASA documented the capabilities needed to execute the Agency's missions for the next 20 years. In addition, NASA evaluated capability gaps and identified potential technologies that could best achieve the desired capabilities. For each potential technology, the team documented the technology state of the art (SOA) and appropriate technology goals.

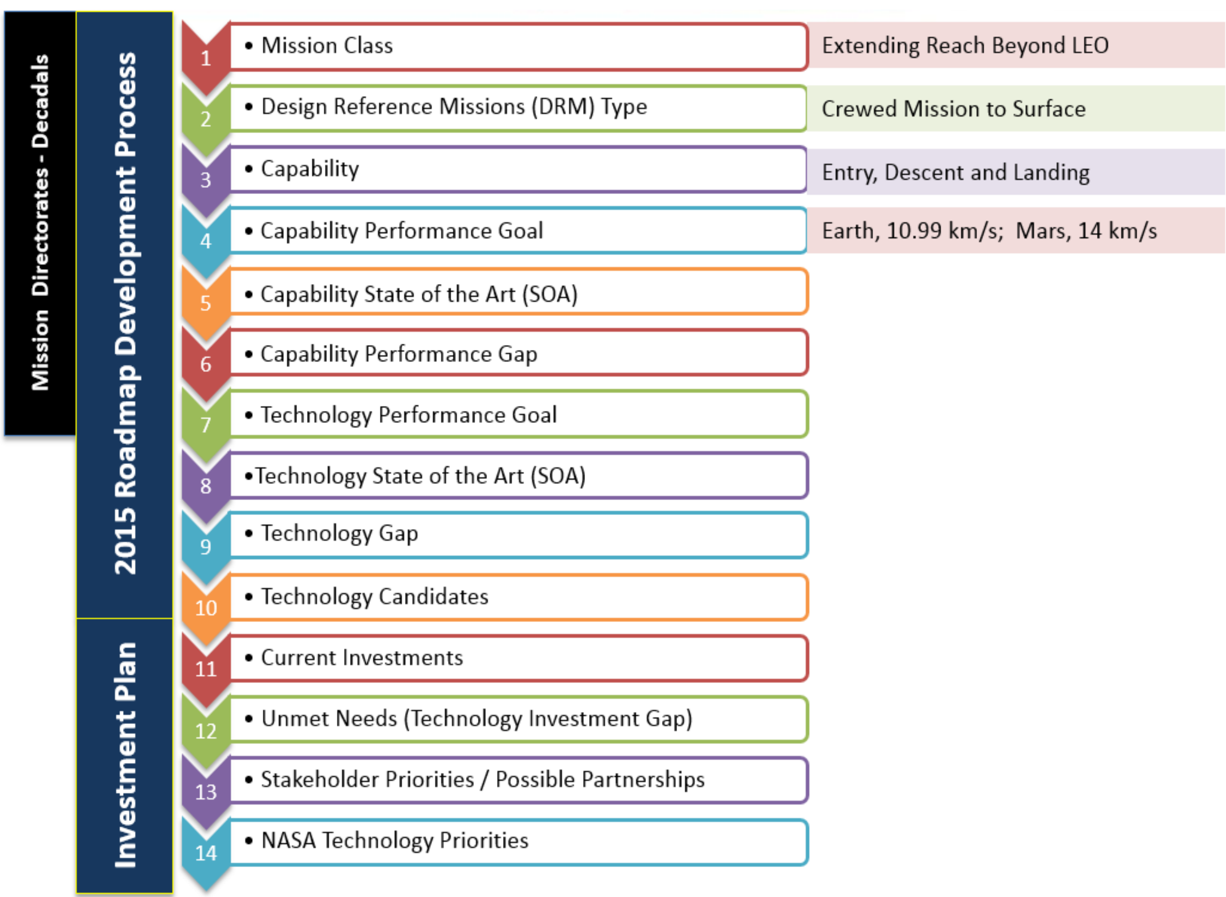

Figure 4. 2015 NASA Technology Roadmap - Development Process

The 2015 NASA Technology Roadmaps expand and enhance the original roadmaps, providing extensive detail about anticipated mission-capability needs and associated technology-development needs. These can be found at http://www.nasa.gov/offices/oct/home/roadmaps/index.html.

The 2015 NASA Technology Roadmaps have 15 Technology Area (Figure 5). Each has an associated set of Technology Candidate Snapshots. The technology candidate is an individual technology nominee with the potential to support one or more planned or conceptual NASA Design Reference Mission(s). The Technology Candidate Snapshot includes the following information about the technology being considered:

1. Technology, including a description, challenge, dependencies, state of the art performance level, and a technology performance goal;
2. Capability needed, including a description, state of the art performance level, and a capability performance goal; and
3. Mission linkages, including the launch date (if determined), the technology need date, and the estimated time to mature the technology.

Figure 5. 15 Technology Areas in NASA's 2015 Technology Roadmaps

To ensure that NASA had appropriately identified the correct set of technology candidates, performance capabilities, and existing state of the art, NASA invited international partners, federal agencies, industry, and academy to provide input. These organizations commented on the technology candidates and identified where collaboration on specific technology development activities would be most fruitful. NASA released a formal request for information, advertised in the Federal Register and Federal Business Opportunities, and sent letters soliciting input to ensure an understanding of the potential uses of NASA-developed technology by the broader space community. The information collected was used during the update of the roadmaps and is being incorporated in the prioritization of the candidates. Currently, the new technology candidates that will help NASA achieve its extraordinary missions are listed in the 2015 NASA Technology Roadmaps.

The updated 2015 Technology Roadmaps enhance and expand the 2012 Roadmaps by responding to NASA's changing needs, advances in technology, and recommended improvements from the National Research Council and other stakeholders. The technologies outlined in these roadmaps focus on applied research and development activities and do not include basic research. These roadmaps include updates from Human Exploration and Operations, Science, and Aeronautics. Consistent with the NASA Strategic Technology Investment Plan, the Roadmaps will produce capabilities that accomplish NASA's goals: to extend and sustain human presence and activities in space; to expand understanding of the Earth and the universe; to explore the structure, origin, and evolution of the solar system; to search for life past and present; and to energize the commercial space enterprise and extend benefits of space for the nation.

The NASA technology candidates in the roadmap are a foundational element of NASA's technology portfolio management process. However, there are many more technology candidates than NASA can afford. Consequently, the Agency must prioritize the candidates and identify those that provide the most benefit to NASA and the Nation. Today, this prioritization is documented in the Strategic Space Technology Investment Plan (SSTIP). The SSTIP was created by NASA following careful review of the 2012 draft roadmaps by the National Research Council (NRC) and incorporated the recommended priorities from the NRC, combined with input from the public and key stakeholders. The SSTIP is being updated and is anticipated to be released in FY2017. With these technology priorities in hand, NASA uses a senior decision-making body, the NASA Technology Executive Council (NTEC), to make recommendations on NASA's technology policy, prioritization, and strategic investments. This Council meets to evaluate the portfolio, weigh it against the priorities, identify gaps in needed capability and technical solutions, assess technical progress against capability needs, and identify strategies to grow new technical solutions. The technology investment plan coupled with the NTEC decisions directly impacts NASA technology investments internally through NASA's budget process and externally through Requests for Information (RFI), Announcements of Opportunity (AO), NASA Research Announcements (NRAs), grants, fellowships, prizes, and challenges.

V. SMC S&T Roadmap Development

SMC supports the USAF Space Command (AFSPC) in the development of Science and Technology (S&T) roadmaps. These efforts are done in parallel with the Core Function Support Plan (CFSP) development activity that S&T capabilities must support. The S&T roadmaps focus on developing enabling technologies that must support future capabilities in AFSPC mission responsibilities, which include Space and Cyber. The capabilities that we can best collaborate on with NASA are pervasive capabilities that support both agencies.

In November 2014, SMC/ST met with NASA OCT in NASA-HQ. At that meeting, NASA requested SMC/ST to assist NASA with S&T roadmap development. On July 2015, a telecom occurred between the SMC/ST, selected attendees from AFRL/RV, and representatives from NASA's Office of the Chief Technologist. It was requested at that time by SMC/ST that NASA align its technology candidates to the top 70 Air Force technology need areas that had the best potential for collaboration. The goal is that, ultimately, NASA and the Air Force Space and Missile Systems Center will be able to reach 2-3 technology need areas where there is strong potential for collaboration. These S&T areas include Solar Electric Propulsion (SEP), proximity operations, and on-orbit logistics.

As NASA works with the Space and Missile Systems Center (SMC) to identify mutual areas of interest, the NASA Technology Roadmap technology candidates are instrumental in the discussion. The candidates enable very specific conversations about advancing state of the art to reach specific performance goals that address pervasive needs. Using the roadmap candidates, the federal government can identify state of the art, current investments, and future needs. Federal employees can share information about existing partnerships and collaborations, contractors, and resources (e.g., personnel and facilities), thereby ensuring the Nation produces the greatest benefit using the taxpayers' dollar. Additionally, the agencies can determine who is leading a specific technology development area and where future collaborations can be used to tackle difficult problems.

SMC/ST conducted the effort in July and August 2015 (Assisted by SMC Advanced Systems Science and Technology – SMC/ADYT branch). 47 of 100 AFSPC tech needs appeared to correlate to 44 of 354 NASA tech needs. The team identified 70 total matches -- each NASA or AFSPC tech need (TNs) can match to one or more of the other's tech needs. Of the AFSPC TNs that matched, 4 had no funding, 24 had partial funding, and 19 were fully funded. 237 NASA technology areas that do not correlate to AFSPC TNs may be useful to AFSPC; these are lower priority TNs that did not make the cut. There were 73 NASA technology areas found to have little or no application to AFSPC needs. SMC/MC (Milsatcom) and SMC/SY (Space Superiority) reviewed and agreed with results that were provided to NASA.

Figures 6, 7, 8 below provide an illustration of both the breadth and fidelity of the S&T Crosswalk performed by SMC and NASA. Figure 7 is a close-up showing some of the detail that cannot be observed in Figure 6.

In order to complete this analysis NASA mapped each of the technology need areas identified in the spreadsheet provided by AFSPC into the appropriate NASA Technology Roadmap areas. Then, individual NASA technology candidates were identified within those technology need areas where AF SPC believes there to be potential for collaboration. A table was developed, listing each of the promising technology candidate number with its description. There are 264 technology candidates listed in the tables. Figures 6, 7, 8 below present some of the mechanics to arriving at our S&T synergy recommendations. With that feedback, NASA is able to call out the appropriate technology candidate snapshots for a more in-depth collaboration consideration.

It should be noted that only some of the technologies in the 2015 NASA Technology Roadmaps are currently funded. NASA is in the process of prioritizing all of its technology candidates in order to identify the most significant needs. The AFSPC interests will be considered in that prioritization process, which will influence future funding consideration. This effort provides the groundwork for a future S&T Forum in 2016 among NASA, AFSPC, and other agencies.

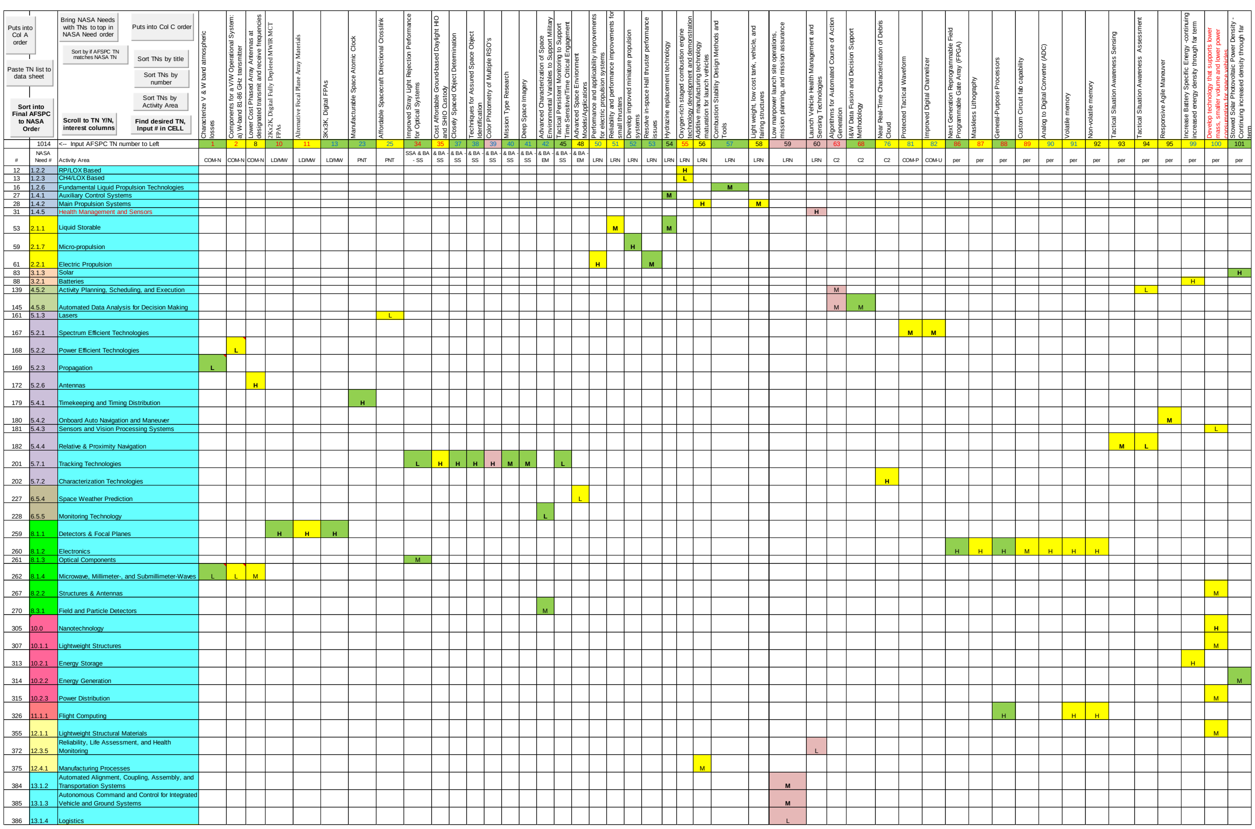

Figure 6: The Breadth and Fidelity of the Original S&T Crosswalk

NASA Need #	AFSPC Need #	Degree of Correlation	Funding	Impact	Activity Area	NASA Order #	AFSPC Order #	NASA Title
8.1.1	1034	H	Y	H	LD/MW	259	11	Detectors & Focal Planes
5.2.2	587	L	Y	H	COM-N	168	2	Power Efficient Technologies
5.2.6	241	H	Y	E	COM-N	172	8	Antennas
8.1.4	587	L	Y	H	COM-N	262	2	Microwave, Millimeter-, and Submillimeter-Waves
5.7.1	1030	H	Y	H	SSA & BA - SS	201	35	Tracking Technologies
5.7.1	1031	H	R	M	SSA & BA - SS	201	39	Tracking Technologies
1.2.2	384	H	Y	H	LRN	12	55	RP/LOX Based
8.1.1	861	H	G	H	LD/MW	259	10	Detectors & Focal Planes
8.1.2	1019	H	Y	H	per	260	87	Electronics
4.5.2	1042	M	R	H	C2	139	63	Activity Planning, Scheduling, and Execution
4.5.8	1042	M	R	H	C2	145	63	Automated Data Analysis for Decision Making
5.2.3	960	L	G	H	COM-N	169	1	Propagation
8.1.4	960	L	G	H	COM-N	262	1	Microwave, Millimeter-, and Submillimeter-Waves
8.1.4	241	M	Y	E	COM-N	262	8	Microwave, Millimeter-, and Submillimeter-Waves
1.4.5	1015	H	R	E	LRN	31	60	Health Management and Sensors
2.2.1	761	H	Y	M	LRN	61	50	Electric Propulsion
3.2.1	714	H	Y	M	per	88	99	Batteries
8.1.1	702	H	G	M	LD/MW	259	13	Detectors & Focal Planes
8.1.2	737	H	G	H	per	260	86	Electronics
8.1.2	743	H	G	H	per	260	88	Electronics
8.1.2	736	M	Y	H	per	260	89	Electronics
8.1.2	732	H	Y	M	per	260	90	Electronics
8.1.2	750	H	Y	M	per	260	91	Electronics
10	964	H	Y	M	per	305	100	Nanotechnology
10.2.1	714	H	Y	M	per	313	99	Energy Storage
11.1.1	743	H	G	H	per	326	88	Flight Computing
11.1.1	750	H	Y	M	per	326	91	Flight Computing

Figure 7: A Close up Sample of the S&T Crosswalk

NASA Need #	AFSPC Need #	Degree of Correlation	NASA Title	AFSPC Title
1.2.2	384	H	RP/LOX Based	Oxygen-rich staged combustion engine technology development and demonstration
1.2.3	384	L	CH4/LOX Based	Oxygen-rich staged combustion engine technology development and demonstration
1.2.6	301	M	Fundamental Liquid Propulsion Technologies	Combustion Stability Design Methods and Tools
1.4.1	760	M	Auxiliary Control Systems	Hydrazine replacement technology
1.4.2	1014	H	Main Propulsion Systems	Additive manufacturing technology maturation for launch vehicles
1.4.2	1002	M	Main Propulsion Systems	Light weight, low cost tank, vehicle, and fairing structures
1.4.5*	1015	H	Health Management and Sensors	Launch Vehicle Health Management and Sensing Technologies

Technology Area Snapshot Candidate	Snapshot Candidate Technology Name	Snapshot Candidate Description
2.2.1.7	Miniature Hall Thruster	Hall thrusters are electrostatic thrusters that use a cross-field discharge described by the Hall effect to generate and accelerate the plasma.
2.2.1.8	Miniature Ion Thruster	Provide thrust by a variety of plasma generation techniques to ionize a large fraction of the propellant. High-voltage grids then extract the ions from the plasma and electrostatically accelerate them to high velocity at voltages up to and exceeding 10 kV.

2.2.1.9	Resistojets	Resistojets use an electrically-heated element in contact with the propellant to increase the enthalpy prior to expansion through a nozzle.
2.2.1.10	Arcjets	Arcjets use an electric arc to heat the propellant prior to expansion through a nozzle.
2.2.1.11	Variable Specific Impulse Magnetoplasma Rocket (VASIMR)	VASIMR is a high-power radio frequency driven plasma thruster capable of I /thrust sp modulation at constant input power scalable over a broad range of power levels using efficient power processing units (PPUs) based on existing commercial radio broadcast technology.

Figure 8: Sample Need Areas Associated with NASA Technology Area 01: Launch Propulsion Systems

NASA led discussions with the Thermal Protection Systems (TPS) experts from NASA, Office of the Under Secretary of Defense (OSD) for Acquisition, Technology and Logistics (AT&L), OSD Research and Engineering (R&E), AFRL - Materials and Manufacturing, and AFRL - Space Vehicles, the U.S. Army Aviation & Missile Research Development & Engineering Center (AMRDEC), and the Naval Surface Warfare Center. The organizations discussed current and future investments, critical needs, and potential areas of collaboration. The first meeting spawned a number of activities, including the identification of possible test equipment for collaborative use and multiple site visits. As a result of this effective and collaborative environment, there were substantial results, including the joint development of a training course for new TPS engineers and a NASA-Army collaboration on further development of 3-D woven carbon-carbon material produced by NASA's Heatshield for Extreme Entry Environment Technology (HEEET) project (See Figure 9). With Army support, NASA's HEET project was able to conduct exploratory testing using the DoD Arnold Engineering Development Center (AEDC) facility. Additionally, The U.S. Army executed a contract to further develop the TPS material using the approach pioneered by NASA, which has the potential to reduce fabrication cost and shorten schedule time. The Army considers this technology to be a breakthrough, one that enables systems design. In turn, NASA partnered with AMRDEC to create a materials database that supports both organizations. OSD AT&L considers the new coalition to be so successful that they have requested additional meetings to identify other opportunities for technological collaboration.

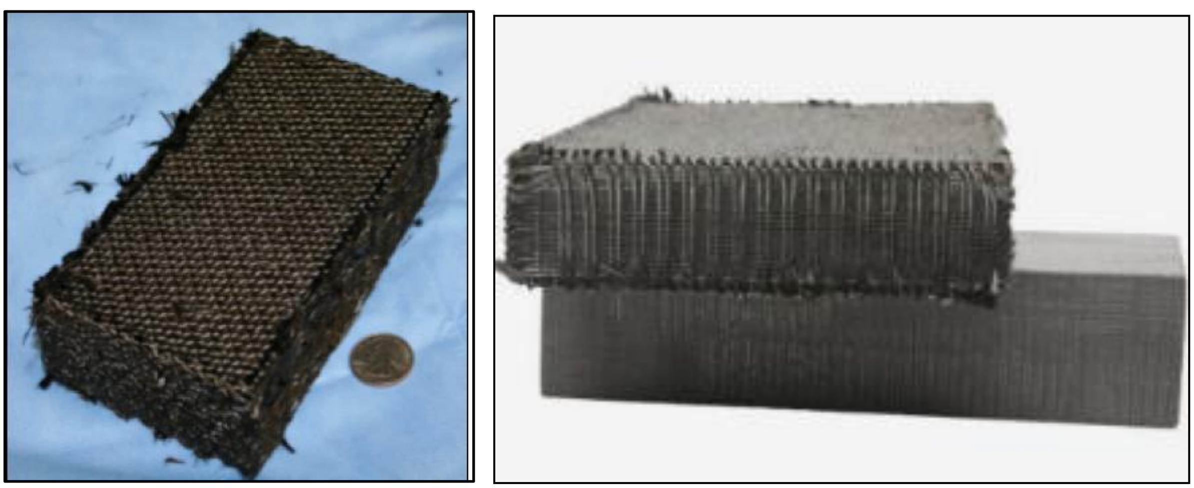

Figure 9. NASA Heat Shield for Extreme Entry Environment Technology (HEEET) ---NASA may benefit from Army's work

VI. S&T Partnership Forum Collaboration

The Science and Technology (S&T) Partnership Forum is a strategic forum established to identify synergistic efforts and technologies. It is chaired by the Chief Scientist from Air Force Space Command (AFSPC) and has three lead Agencies: Air Force (AF), NASA, and other agencies. Additionally, the forum has participation from the OSD R&E, Naval Research Laboratory (NRL), DARPA, and the National Oceanic and Atmospheric Administration (NOAA).

The forum has a near-term goal of actively working to crosswalk NASA-AF-other agencies roadmaps to identify opportunities for synergy and collaboration in technology investments. The forum will develop a strategy to produce a joint roadmap that focuses on a mutually beneficial long-term goal. The S&T Partnership Forum is accomplishing this strategy development through personnel exchange (e.g., AFRL has been on detail to NASA Headquarters, Office of the Chief Technologist, traveling to NASA HQ monthly). Additionally, the forum has held multiple technical interchange meetings (TIM).

One TIM was held to identify pervasive technologies that would provide the first opportunity for a detailed crosswalk. NASA hosted this TIM, where the S&T Partnership Forum generated 16 technology topics. These topics were prioritized within each Agency based on their own criteria, and then integrated and prioritized across the agencies by identifying topics that provided mutual benefit and potential for future collaborative work. These include small satellite technology development, big data analytics, in-space assembly, cybersecurity and assured access to space.

To pilot the development of an integrated roadmap, in June 2016 the S&T Partnership Forum chose to focus on one area: small satellite technology, with a focus on developing miniaturized sensing capabilities for cube-sat and small-sat platforms. Miniaturized operational sensors can form a resilient source of data. Additionally, they can be gap fillers in space architectures because sensors on all tactically-responsive spacecraft could be easily adapted to reconfigurable constellations. In July 2016, the forum members met to report on current investments in the area of small satellite miniaturized sensors: optical, energetic charged particle, electromagnetic, local spacecraft environment, and sensor web technologies. The goal was to identify key sensor technologies with the most cross-agency impact (e.g. weather sensor, space environment sensor, optical sensors, etc.). Later the organizations will work to develop an integrated technology roadmap and coordinate work in this area. Progress on this activity was briefed at the 30th Annual Small Satellite Conference, August 11, 2016 at Logan, Utah. The S&T Partnership Forum will report their progress at the AF-NASA and other agencies Summit in Washington D.C, December 2016. Taking feedback from senior leadership, the S&T Partnership Forum will continue with the development of the roadmaps, looking for opportunities to leverage investments, collaborate, and build a strong national technology development capability.

VII. Solar Electric Propulsion (SEP)

As indicated above, most space missions could greatly benefit from the enabling technology of high output solar arrays, combined with powerful, more efficient electric propulsion (top NASA technology priorities: launch propulsion and in-space propulsion). Future solar arrays could provide output over 100 kW and advanced solar electric propulsion systems can significantly improve launch enterprise architectures and performance[35]. This AIAA Space 2014 paper demonstrates how the SMC launch enterprise can be re-imagined by using a LEO orbit as the standard injection orbit, using the SEP-powered spacecraft to complete the transfer to all higher mission orbits. This is depicted in Figure 10 below. SEP-powered spacecraft eliminate considerable mass from chemical propulsion fuels and oxidizers that traditional spacecraft currently required for orbital transfer.

Significant potential benefits include:

1) Downsizing spacecraft and launch vehicles

2) Lowering fleet-wide architecture costs: smaller boosters, dual launching, and possibly launching all vehicles from a single launch site

3) Increased maneuverability

4) Increased resiliency ("graceful" failure mode with multiple SEP engines)

5) More efficient and effective constellation management

6) Providing extra power and enabling enhanced payload capability and performance

7) Enhanced end-of-life options (possible de-orbit) and reduced orbital debris

8) Enabling larger launch windows

9) Enabling previously infeasible/impractical missions: maintaining unstable orbits or ground tracks and dynamic orbit change flexibility (high number of orbit changes and repositions)

The paper lists much more information and performance parameters, with a specific focus on the SMC mission set. SEP technology is likely to enhance the capabilities of many space enterprises, including NASA's. Examples include the MGS study (discussed above), as well as other civil, commercial, and international space missions.

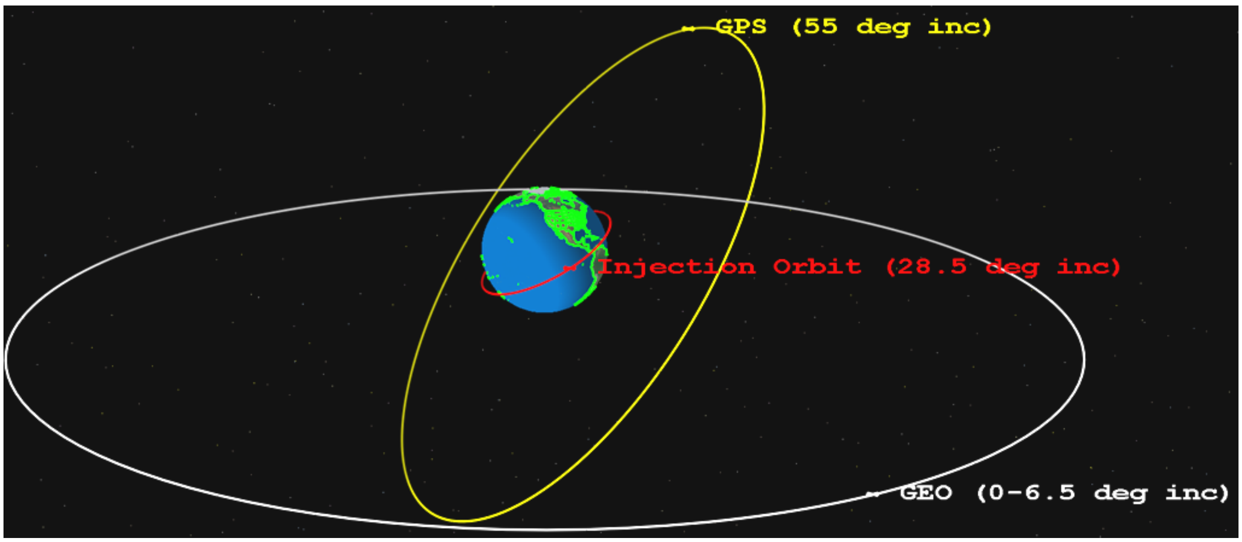

Figure 10: LEO Transfers to Mission Orbits Enabled by Solar Electric Propulsion – Allow for Mix-Manifesting, Enabled by Common LEO Injection Orbit

VIII. USAF AFRL Collaboration

SMC works with Air Force Research Laboratory (AFRL) on many topics. These topics include space-cyber, Quantum Key Distribution (QKD), Carbon Nanotubes (CNT), propulsion, Space Situational Awareness (SSA), and more. One example of this collaboration is on Small Business Innovative Research (SBIR) projects. SMC provides AFRL with S&T topics of interest to SMC missions. In many cases SMC supports AFRL in technical oversight of such projects. Example projects include space High Assurance IP Encryption (HAIPE) for small satellites and QKD projects, among others. SMC personnel participate in design reviews and project milestone decisions as appropriate. This activity tightens the deliveries of SBIR results to AFSPC and SMC needs, and enhances the probability of successful transition to capabilities. Other S&T collaborative activities include big data and cloud computing. SMC recently supported AFSPC and AFRL portfolio reviews for both space and cyber. AFSPC, SMC, and AFRL used these results in order to evaluate promising technologies for the SMC Materiel Innovation Working Group (MIWG) and other collaborations.

IX. Additional Government Collaboration Partners

In addition to NASA, DARPA, and Naval Research Laboratory (NRL), the SMC Chief Scientist Office collaborates with a number of organizations, such as The USAF Office of Chief Scientist (USAF/ST), the USAF Science Advisory Board (SAB), the AFSPC Independent Strategic Assessment Group (ISAG), Space and Naval Warfare Systems Command (SPAWAR), and a number of other services and agencies. In particular, SMC contributed to the USAF Cyber Vision 2025 (CV 2025), which was published in 2012[17]. SMC and AFSPC provided key concepts and contributions to the space-cyber component of the USAF CV 2025. These initial contributions, made in conjunction with AFSPC and AFRL, are guiding the USAF in the development of future space and cyber capabilities.

The document that results from SMC and AFSCP's efforts, "Cyber Enhanced Space Operations (CESO)," is discussed in more detail elsewhere[32]. As we endeavor to better integrate the space mission with the cyber mission, SMClooks forward to enhancing all these USAF guidance documents.

The USAF Rapid Innovation Funding (RIF) program is another program that focuses on the transition of S&T into capabilities. The USAF RIF program is targeting promising S&T results and assists in S&T's successful transition across the "Valley of Death" into actual space capabilities. The USAF RIF program is overseen by USAF/AQR (USAF Acquisition – Science, Technology, and Engineering), and the SMC Chief Scientist serves as the lead Technical Evaluator for Program Executive Officer (PEO) Space topics. The USAF RIF program looks to make small investments ($3M or less) in S&T results that can transition to fielded capabilities within 2 years. Such topics include IP-enabled encryptors for small satellites, carbon nanotube harnesses, and other topics. In most cases these are activities taken on by small, athletic S&T companies. In many cases RIF builds on SBIR (Small Business Innovative Research) projects. The SBIR program is also overseen by AF/AQR, and SBIR Space solicitation topics are recommended by SMC. AFRL is involved in the execution of SBIR programs, with support from SMC as appropriate. The collaboration among these government organizations leverages small investments to best serve the users of these systems.

X. Investment in Our Future Talent – Cultivation of STEM Talent

Human talent is a key enabler of advanced S&T activities. It is absolutely critical to have a strong supply of talent in the fields of science, technology, engineering, and mathematics (STEM). We continually collaborate with the USAF Institute of Technology (AFIT), other service academies and graduate schools, and other universities and colleges. SMC sponsors research topics for AFIT and are involved in a number of other STEM activities. For example, Aerospace and SMC support technical activities at Harvey Mudd College (HMC). These activities include leading the HMC Engineering Visitors Committee, sponsoring annual capstone projects (Engineering Clinics), and service on the HMC Clinic Advisory Committee. These activities grant us the opportunity to mentor STEM talent and provide stewardship advice to educational organizations. Some of the technical capstone projects that we led include: intrusion detection, mobile phone cyber, grid computing, network and enterprise management, orbital analysis, graphical enhancements, and remote monitoring and Internet Engineering[34]. The technical infusion of talent to the workforce is a key contribution to the ability of SMC to manage the development and acquisition of innovative space programs.

XI. Way Forward and Conclusions

This paper highlights the benefits that result in from strategic S&T partnerships and recommends a way forward to continually build upon these achievements into the future. Going forward, SMC and collaboration agencies continue to leverage several collaborations into a consistent progress in S&T innovation and transition to capability. For example, the SMC and NASA S&T collaboration created synergies, the SMC participation in the DARPA F6 program enhanced SMC's position with respect to IP-enabled and fractionated space architectures. SMC's leadership within the Malware Technical Exchange Meeting (MTEM) enhanced the NSS position with Space cyber, as did SMC's contributions to the USAF CV 2025 study. SMC's leadership of the USAF RIF program enabled successful transition of a number of key S&T capabilities to the space enterprise, such as small satellite encryptors and carbon nanotube harnesses that are lighter than traditional harnesses. SMC's and AFSPC's work with NASA and DARPA generated a number of synergies for both on orbit servicing and launch technologies. STEM education and collaboration on a variety of pervasive S&T areas are of great benefit in building our talent pool. Our experimental work on the F6 Tech Package enabled deeper understanding of the hosted payload architectures, as well as space-cyber situational awareness and related research.

As NASA works with the Space and Missile Systems Center (SMC) to identify mutual areas of interest, the NASA Technology Roadmap candidates are instrumental in the discussion. The technology candidates enable very specific conversations about advancing state of the art to reach specific performance goals that address pervasive needs. Using the roadmap technology candidates, the federal government can identify state of the art, current investments, and future needs. Federal employees can share information about existing partnerships and collaborations, contractors, and resources (e.g., personnel and facilities), thereby ensuring the Nation produces the greatest benefit using the taxpayers' dollar. Additionally, the Agencies can determine who is leading a specific technology development area and where future collaborations can be used to tackle difficult problems.

The goal of achieving optimal collaboration is to compare AFSPC and NASA technology needs (TNs) at a top level in order to determine: Which TNs are similar and which NASA TNs may be useful to AFSPC when there are no similar AFSPC TNs? These question will help us prepare for future studies to determine how NASA and AFSPC can leverage and collaborate on technology development programs and road mapping efforts. Exploring these questions has already led to some groundwork for a future S&T Forum in 2016 among NASA/AF and other agencies. The details of this work are provided in the opening paper of this session[36].

SMC would like to continue to grow the S&T collaboration between NASA and SMC, as well as with other agencies. The synergy that S&T activity affords us will likely reduce our overall investments while also increasing the outcomes for multiple agencies going forward.

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